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Towards a multi-scale semantic characterization of the built heritage: From the column to the urban scale

A survey, defined as a succession of stages ranging from acquisition to representation, has historically an ambition of analysis, understanding, and knowledge representation of architectural artefacts. However, there is a paradox. While for many years this discipline has seen a development in digitization methods and techniques, the purpose of the survey seems to mainly focus on the metric representations of building, and on the production of beautiful (or figurative) images. Acquisitions by lasergrammetry or photogrammetry bring in a quantity of data that are qualified as massive, but appears to be too often underlooked. The present paper attempts to consider work acquisition beyond the ambition of the acquisition of measurements, which investigates new methodological approaches for the characterization of architectural shapes according to different scales of observation. To understand whether the data resulting from the acquisition work can assist "beyond the visible" in the study and analysis of built heritage, this paper addresses three methodological avenues, which relates to the morphological / semantic characterization of architectural objects according to different nature and scale, to consider new methods of analysis by using further massive data.

Keywords:
Semantics; 3D digitization; Architectural characterization; Heritage documentation; Survey

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1. INTRODUCTION

For many years, architectural survey has seen the development of digitization techniques and methods and their increasing democratization. Terrestrial and aerial lasegrammetry or photogrammetry allow for considering the constitution of 3D models which are faithful and consistent, both in terms of metric and visual terms (Ioannides & Quak, 2014).
While digital technologies, mobilized in this architectural survey context, offer ways to observe the constructed environment with greater precision and completeness compared to those of thirty years ago, the increasing mass of point clouds, 3D models and other digitization also generate an overload of information (Boehler & Marbs, 2002; Lo Buglio & De Luca, 2011). Current 3D digitization allows for getting closer to the imprint of reality. But the analysis of the surveyed object is then postponed to the post-processing phases. During these phases the mass of data produced is often reduced to find a meaningful and intelligible drawing, which one can be refered to a semantic universe, to a universe of architectural knowledge (Lo Buglio & De Luca, 2011). However, we noted that these approaches are both subjective and can lead to the loss of the complexity inherent of digitized artefacts. Whilst the analysis and enhancement of built heritage require a special attention, 3D data digitization and processing solutions offer few possibilities for using further the complexity of digitized artefacts to produce intelligible architectural representations with cultural and cognitive value.
The present paper challenges the consideration of acquisition work beyond the ambition of the acquisition of measurements. The paper investigates new methodological approaches for the characterization of architectural shapes according to different levels of observation. To understand whether the data resulting from the acquisition work can assist "beyond the visible" in the study and analysis of built heritage, this paper addresses three methodological avenues, which relate to the morphological characterization of architectural objects according to different scales and logics (semantic, stylistic and spatial), to consider new methods of analysis that further use massive data.
The first avenue concerns the study of morphological similarities at the column scale. More than any other element, a column crystallizes the compositional orientations of many architectural styles. Based on the systematic digitization of all columns of a Roman cloister, the aim is, in this case, to produce the morphological signature of each column using a semi-automatic approach. Such signatures reflect the semantic discontinuities and surface curvatures specific to each entity. Beyond the study of the morphological similarities shared by the corpus, these signatures allow for opening up interesting perspectives in the study of stylistic propagations in space and time.
The second avenue concerns the semantic study of facades, which one aims, on an architectural scale, to locate the morphological variations of the facades that make up seven of the most important French royal squares built between the 17th and 18th centuries. Such study attempts to verify the hypothesis of a codified composition common to all these places. To understand what brings them together, and above all to prove the historical links that bind them, a span of each square is digitized. As for the elements studied at the lower scale, a semi-automatic analysis method similar to the previous one (that was based on the calculation of curvatures maps) is implemented. The signatures of each span are then made to capture the morphological and semantic structure, as well as their compositional consistency.
Finally, the last avenue concerns the urban scale, which one is more about applying the semi-automatic analysis methods developed to an archaeological urban context rather than understanding the morphological similarities of a collection of digitized objects. In this case, the study is based on the photogrammetric survey of the archaeological site of Pachacamac in Peru. This survey carried out by drone made it possible to digitize several tens of hectares for refining our understanding of the spatial organization of the "city". As in the previous cases, the curvatures of surfaces were analyzed from 3D digitization to highlight building and circulation networks not directly visible from the ground or from aerial images. As a prior step for the developement of space syntax analysis, this approach seeks to demonstrate the value of using massive data to highlight urban structure and to identify circulation systems.
Through the semi-automatic assistance methods proposed for architectural analysis, the challenge is to open up new avenues for the exploitation of 3D digitizations. By implementing this approach to characterizing the built heritage on three different architectural scales, we wish to demonstrate the interest and relevance that these methods might have in the development of a multi-scale knowledge of the built heritage.

2. FROM DATA TO ARCHITECTURAL CHARACTERIZATION

This work aims to question contemporary survey practices, and, to implement methods of assistance for the morphological analysis of massive data. This involves exploring instrumentations and a methodology based on the graphic representation of the building to assist the researcher with architectural analysis.
The integration of digital technologies in the study of built heritage has the effect of locating the object of the survey outside the semantic field and therefore outside the architectural lexicon. The practice of survey appears to be more disconnected from its cultural and cognitive aims insofar as it first tends towards an approach centered on the data acquisition rather than on their meaning.
However, in recent years, communities concerned by the documentation of built heritage (architects, art historians, archaeologists, curators) have become aware of the problem of data overload and the lack of intelligibility of representations. For example, the number of research carried out on the processing of massive data (De Luca et al., 2007; Haegler et al., 2009; Manferdini et al., 2008; Shalunts et al., 2011) express the need to organize and structure 3D data around games of knowledge about the building.

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Many of these works can be brought together under the term [1] "high-level" approaches, i.e., in which the analyst reduces data to only keep those able to consolidate an intelligible model based on pre-structured knowledge of the field.
In this context, it seems necessary to complement these "high-level" approaches with "low-level" (non-interpretative) approaches, which latter are based on the complexity of the data acquired and, in which the meaning of the elements comes from a "free" estimation of morphological properties, not from architectural shape thesaurus [2]. Based on the study of singular elements, image analysis and statistical analysis might help identifying the morphological/ semantic similarities shared by the elements of a corpus and/or the identification of imperceptible morphological structures.
The "low-level" approach may help with the classification of architectural styles and has interesting implications for the morphological characterization of structures at the urban scale. In the case of large-scale archaeological sites, field data often come from very heterogeneous sources (e.g., excavations, tacheometer, LIDaR, geophysics, multispectral and thermal imaging, photogrammetry). This mass of data must then be crossed to refine our understanding of the place (Jockey, 2013). Since its development in the late 1970s, space syntax has regularly been used as a toolbox for the analysis of spatial configurations (Hillier & Hanson, 1984; Turner et al., 2001). However, such tools require prior knowledge on how to use them to get consistent results (Spence-Morrow, 2009). In other words, to study the movements within an archaeological site, one must determine/model their routes, which often turns out to be complicated given the conservation status of sites.
However, these approaches first require the identification of the built structures, as well as of the traffic networks and their hierarchy. Unfortunately, studies using space syntax analysis methods are often performed to examine urban typologies that are relatively well-known or with modest size (Battistin, 2021; Morton et al., 2012; Wernke, 2012). In some less well-known, more complex, or simply highly altered archaeological contexts, non-invasive prospecting methods are necessary. In some cases, these surveys might easily be achieved by using indicators that are visible on aerial photographs, such as cast shadows or differential vegetation growth (Poirier et al., 2017). However, the climatic and environmental conditions do not always allow such approach. Considering the technical and methodological issue that can support "low level" examination of site digitization at the urban scale is therefore a key first step to be undertaken.

3. A THEORETICAL ROMAN COLUMN BASED ON THE STUDY OF DIGITIZED MORPHOLOGICAL SIMILARITIES

The first observation scale deals with a corpus of architectural elements. Based on some thirty Romanesque columns, this study investigates the modalities for examining the morphological similarities shared by a collection to offer a morphological/semantic signature common to the corpus. If the creation of a signature is not akin to a method of analysis per se, it renews the analyst's gaze and offers a synthetic reading on the collection.

Fig. 1 - Photo of the south gallery of the cloister of the Abbey of Saint-Michel de Cuxa. Image: Gamsau-MAP (CNRS), 2010.

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This approach was applied to the 31 Romanesque columns from the cloister of the abbey of Saint-Michel-de-Cuxa, located in the Eastern Pyrenees (France) (fig. 1). This place was built in the 12th century and was largely destroyed during the 20th century. The choice focused on a set of forms bearing meaning on the scale of the architectural survey, such as "column". It reflects and condenses the technical and stylistic orientations of many currents in the history of architecture. To support this approach, representation systems combining the latest developments in image-based modeling and architectural photogrammetry have been mobilized to digitize all the columns of the cloister.
Based on the principle of self-extension of a dataset, the approach aims to automatically identify a geometric structure common to the collection, its morphological signature. This is the result of a work of morphological and statistical analysis that geometrically characterizes the corpus.
Similarly to the idea that fingerprints are not suitable for identifying an individual's personality, the morphological signature does not reveal the deep stylistic nature of a collection, although it provides a unique and distinctive imprint. Therefore, this signature might not be suitable for the graphic representation of a digitized artifact nor a "theoretical model".
In this study, the signature expresses two characteristics of each entity: the surface curvature, and, the shape discontinuities (fig. 2 & 3). Indeed, most shapes can be described by their surface properties and the discontinuities that shape them up. Looking into more details at this second aspect, the study of discontinuities allows for understanding the different semantic joints present in the column. The term "shape discontinuities" means that every significant change in the surface is marked by a clearly perceptible variation; which is when the variation (angulation) exceeds an "n" deformation factor.
Since the majority of shape descriptors are in the field of 2D image analysis, the first issue is to convert the general complexity of each digital instance into a two-dimensional system, a usable representation (Peura & Iivarinen, 1997; Van Droogenbroeck, 2003; Zhang & Lu, 2004). The polygonal digitization of each column is then projected onto a cylindrical envelope (archetype of the column), where the distance in between them (column and envelope) is encoded in grey level (fig. 3, upper part). The result is a 2D depth map that implicitly contains (grey shades) all the morphological information needed for a three-dimensional reconstruction of the object.
In the study of shapes, image analysis algorithms provide opportunities for contour extraction, line identification and analysis of similar regions, amongst other usage. The benefits and limitations of these descriptors were tested on each depth map of the corpus. Among the shape descriptors explored, the contour segmentation operator, "Hough Standard Transform" (SHT), is an automatic pattern recognition technique [3] used for the detection of linear networks within an image (Maître et al., 2001). The SHT method was therefore adapted, configured and coded to detect all the linear networks presented on the thirty-one depth maps (Lo Buglio et al., 2015). The automatic identification of the lines traversing a depth map allows for locating all the semantic articulations (articulations between two sub-entities) between the plinth and the lower torus, the lower torus and the upper torus, the upper torus and the shaft, etc. As mentioned above, a shape can also be described from its surface curvatures. These latter correspond to the mathematical expression of the variations of a surface in each of its points.

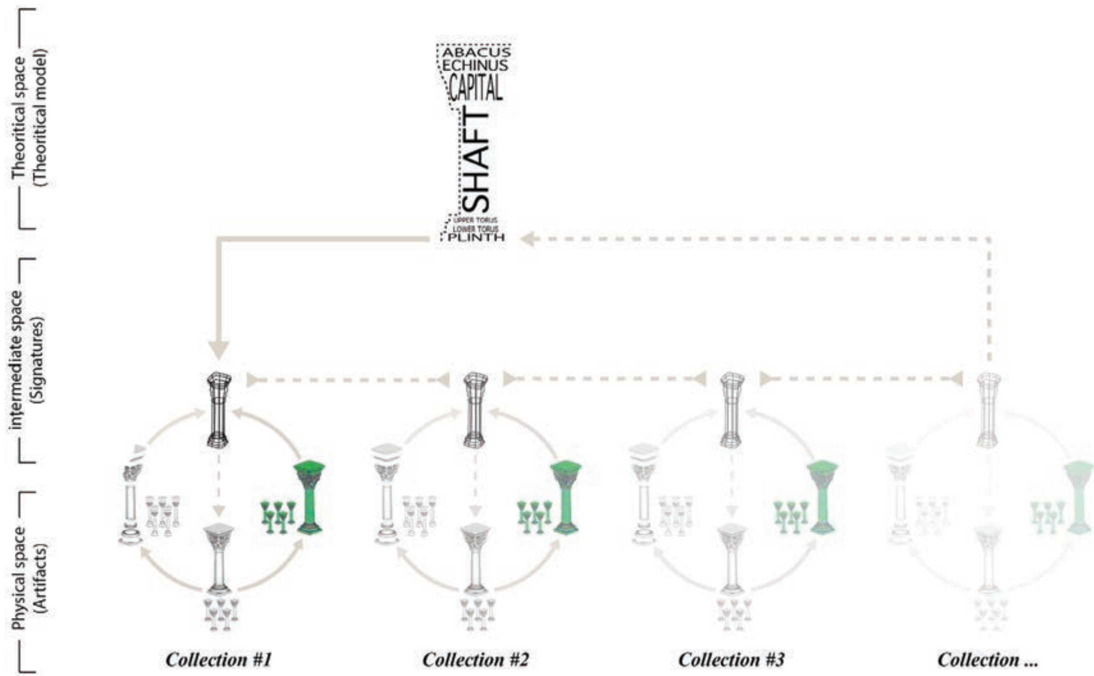

Fig. 2 - Methodological approach for the characterization of architectural elements; bringing together a "high-level" approach and a "low-level" approach. Morphological analysis of data from digitized artefacts (physical space); Creation of a signature by collection of elements (intermediate space); High-level observation of signatures and putting them in relation to the evaluation of the "theoretical model" (theoretical space).

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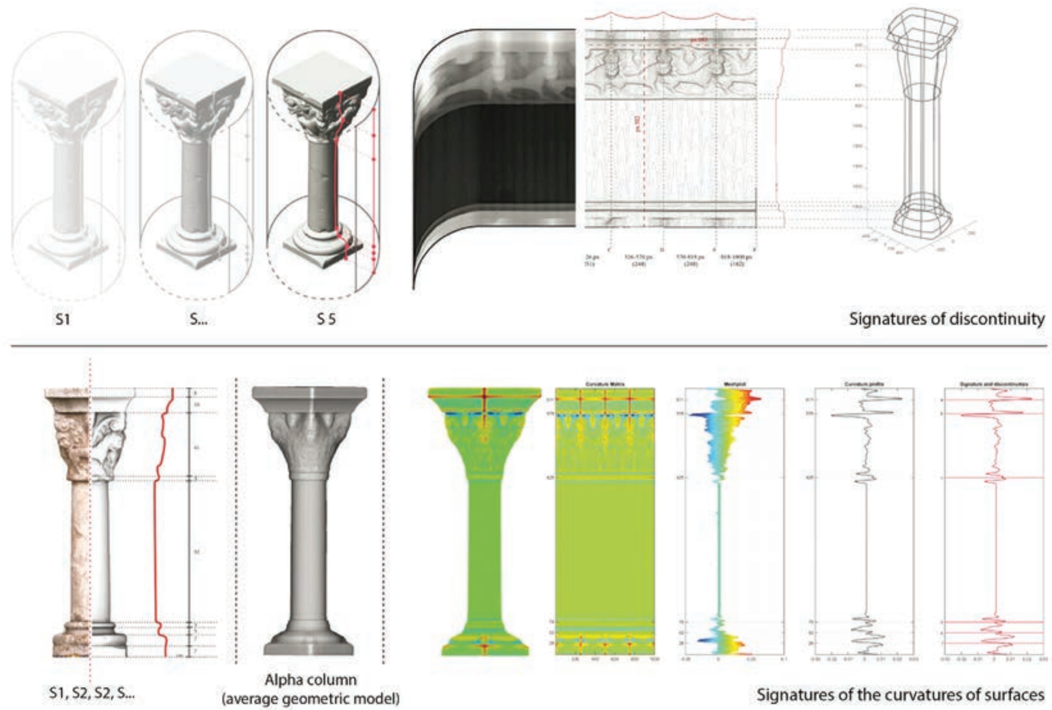

Fig. 3 - Methodological approach for the characterization of architectural elements; bringing together a "high-level" approach and a "low-level" approach. Morphological analysis of data from digitized artefacts (physical space); Creation of a signature by collection of elements (intermediate space); High-level observation of signatures and putting them in relation to the evaluation of the "theoretical model" (theoretical space).

While technical considerations will be further discussed in the next section, the study of curvatures allows for an effective mathematical approach to the geometric characterization of any surface.
The intersection of the two geometric attributes on the entire corpus has led to a signature which provides a new prism of reading the Romanesque column of Cuxa (fig. 2 & 3) without offering a true "theoretical model". For more information on the technical and methodological aspects of the study (and the implementation of signatures), we refer the reader to the paper: "What do 31 columns tell about a "theoretical" 32nd? " (Lo Buglio et al., 2015).

One example of the observations that demonstrates these signatures is by delving into an observation devoid of preconceptions. In this example, it is interesting to note that the signatures of discontinuity and curvature present a double astragalus, whereas the average calculation of positions, diameters and volumes of thirty-one astragalus result into a shapeless object [4] like a flattened torus. However the signature seems to be telling another story. One may question the reason for showing two distinct positions. The historian Olivier Poisson explains these differences by the anastylosis of the cloister in the middle of the 20thcentury, for which some capitals of the tribune-jubé were tried to complete the columns of the west wing (Poisson, 2015). Without going further into the historical analysis, the emerging questions from looking at the signatures are appropriate for reaching the interest of a general "low level" geometric examination.This approach could have interesting implications for the study of degradations and alterations of the building and for the study of stylistic propagations in space and time, with an obvious interest in the classification of shapes.

4. STYLISTIC AND SEMANTIC VARIATIONS OF FACADES OF THE FRENCH ROYAL SQUARES

The second study [5] focuses on the analysis of elements at the architectural scale (Deldaele & Ricbourg, 2018) by examining the spans of the facades belonging to seven remarkable French royal squares. These squares, built around the 17th century, offer an important stylistic coherence.
Through the photogrammetric survey of a span of each square, the challenge is to cross their semantic structures to demonstrate the existence, or not, of common compositional and stylistic rules to serve the political issue of asserting a royal authority through the entire French territory. These places were to ensure the representation of the monarchy throughout France. A representation also ensured by the systematic presence of an equestrian statute of the King but also and above all by the setting formed by a set of buildings (private mansions) responding to a codification guaranteeing their aesthetic and stylistic homogeneity. The supported hypothesis is that these places respond to strict compositional logic that uses a module. These facades articulate ordered spans repeating themselves in a more or less important sequence to form each wing of the squares. To support our approach, 7 royal places were studied. All of these places commonly showed that they were either designed by Jules Hardouin-Mansart as the architect of King Louis XIV, or created after him. Considering the major role of Hardouin-

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Mansart in the systematization of educational rules, it seems legitimate to focus initially on the places which are subsequent to it. These are:

1. la Place des Victoires, Paris
2. la Place Vendôme, Paris
3. la Place de la Libération, Dijon
4. la Place de la Bourse, Bordeaux,
5. la Place du Parlement- de-Bretagne, Rennes
6. la Place Stanislas, Nancy
7. la Place Royale, Reims

For each of these places, their compositional logics were taken into account by relying on the polygonal mesh resulting from the photogrammetric survey of each span. Each span articulates a set of architectural elements that can clearly be identified for their geometric logic; a codification based on the precise articulation of architectural concepts. Each span offers a unique semantic structure.
It is not a question of considering the object as a set of articulated terms but of understanding the relations existing between them. It is in this tension that the "architectural semantics" fits.
Semantic characterization is undoubtedly the most tangible part of what founds the architectural survey, because it requires establishing a relationship between a geometric universe and a terminological universe. This type of characterization and its visual expression are probably the best guarantee of producing intelligible representations [6]. Semantic study is a foundation of architectural analysis; an exercise aiming at putting into perspective the "physical" within the "concepts" world. Semantics exists only through the series, the similarity and the regularity of an existing relation, within a given corpus, between an architectural term and what it evokes on the functional (or symbolic) and formal level (Académie française, 1932).
For the semantic characteristics of the squares, each span has carefully been read from the vocabulary of Préouse de Montclos (Pérouse de Montclos, 2000) on three levels of granularity: the facade, the floor, and the element (see example of the Place Vendôme, fig. 4).

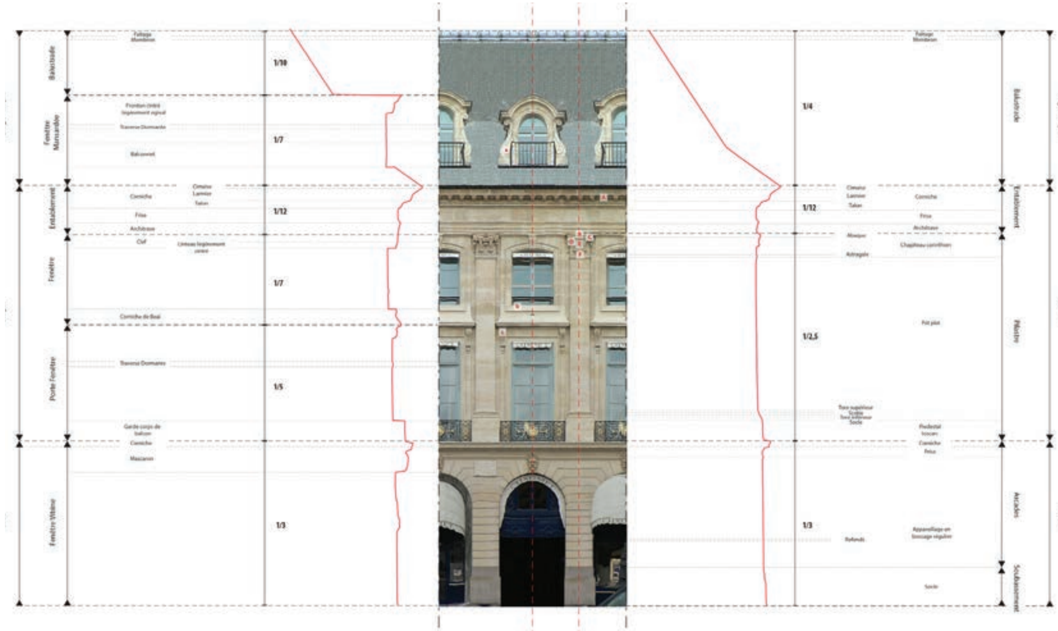

Fig. 4 - Semantization of a span of the Place Vendôme in Paris by Jule Hardouin-Mansart.

In addition to the semantic examination of each span, their morphological characterization might allow for understanding the compositional rules and semantic logics. One of the challenges is to identify the relationships that link geometric and semantic attributes for all squares as to identfy the existence of common compositional rules.
The study of curvatures offers an efficient mathematical approach for the geometric characterization of a surface. As any surface can be described from the knowledge of its curvatures that correspond to the expression of the local variations of the shape at each of its points, this study accounts for estimating each point forming the surface to quantify "by how much the curve bends".To determine the geometric characteristics, curvature maps were thus produced for each span to extract a distinctive signal (fig. 5).

A value is determined for each polygon from its main curvatures (fig. 3, lower part). The product, the mean, or the sum, of the absolute values of the two principal curvatures at each point are typically studied. For example, the product of the principal curvatures corresponding everywhere zero expresses the developable character of the surface. If the result of the product of the curvatures is positive, it indicates the same direction of the curvatures. In contrast, a negative value of the resulting product indicates a surface with opposite directions. The "signatures" carried out by a semantic approach from the curvature maps of all the squares allow for locating the major divergences or similarities within the corpus (fig. 6). As a reminder, the positive and negative oscillations of the profiles reveal a more or less important geometric change corresponding to the semantic variations.

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Fig. 5 - Curvature maps. From left to right, Place de la Liberation in Dijon, Place Royale in Reims, Place du Parlement-de-Bretagne in Rennes and Place Vendôme in Paris.

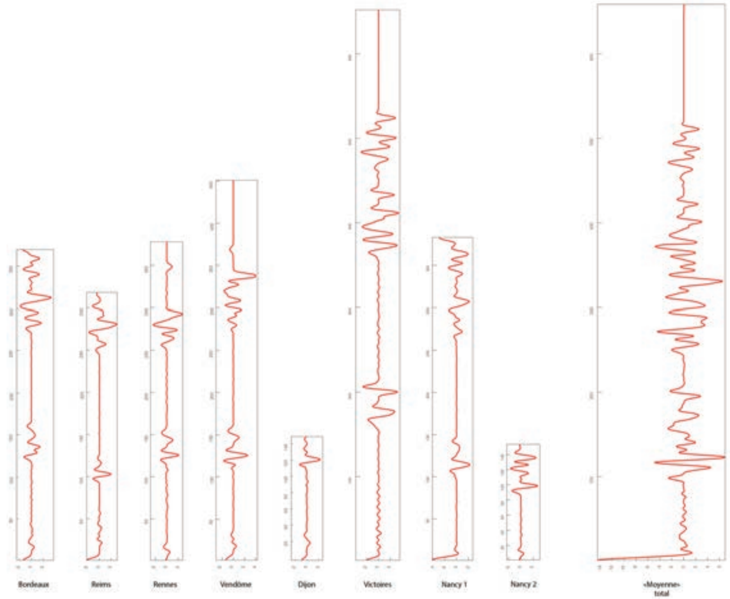

Fig. 6 - Geometric signatures (at order level) for each facade and geometric averaged signature.

An averaged signature was then produced to enrich the transverse reading between the 7 squares (fig. 6). This mean signal does not correspond to any place but intersects with the morphological characteristics of all the squares. The production of this averaged signal aims foremost to provide an observation tool allowing for identifying the divergences or similarities of the corpus (fig. 7). By comparing each of the signatures with the averaged signature, several zones sharing similar values can be identified asthe signals (values of curvatures) follow the same progression with similar orientations in many points. The visual signatures of the curvature maps, compared to the averaged signature, interestingly show an important correspondence at the first levels despite the different heights of the spans. In addition, an in-depth examination of the signatures shows that the Place Vandôme is the closest place to the averaged signature (fig. 7). On the other hand, the Place des Victoires (first place built by Jules Hardouin-Mansart) seems completely disconnected from the rest of the corpus because of its height and its proportions. Such discrepancy might be explained by the nature of the order. This place would have been indeed the only one carried out privately.
Beyond these peculiarities specific to the Place de Victoires, the strong geometric and semantic similarities between the signatures of 6 places (and the significant correspondence between the Place de la Liberation de Dijon and the averaged signature of the corpus) resonably suggest the existence of an architecturale order and rules of composition dictated by their construction.
This first examination suggests the extension of the study to more royal squares would strengthen the hypothesis of rules dictated by the Royal Academy for their construction (fig. 8). More than an aesthetic matter, it was a question of ensuring, through architecture, a royal representation throughout the territory.

5. CIRCULATION NETWORK OF AN URBAN ARCHAEOLOGICAL SITE

Finally, the third case study aims to consider the use of massive data from photogrammetric survey campaigns at the scale of an urban territory. Unlike the previous two cases, it focuses on the contribution of using such data in the context of a ruin. We are no longer talking about classification based on a corpus but of a means to observe other dimensions such as circulation systems. However, the "low-level" approach, and in particular the use of curvature maps, allow for the identification of different urban networks. In this case, it is about identifying the voids and prioritizing them to resonate on possible circulation systems.
This research is based on the archaeological complex of Pachacamac, a desertic area of approximately 600 ha, located on the southern outskirts of the city of Lima on the central coast of Peru (Eeck-

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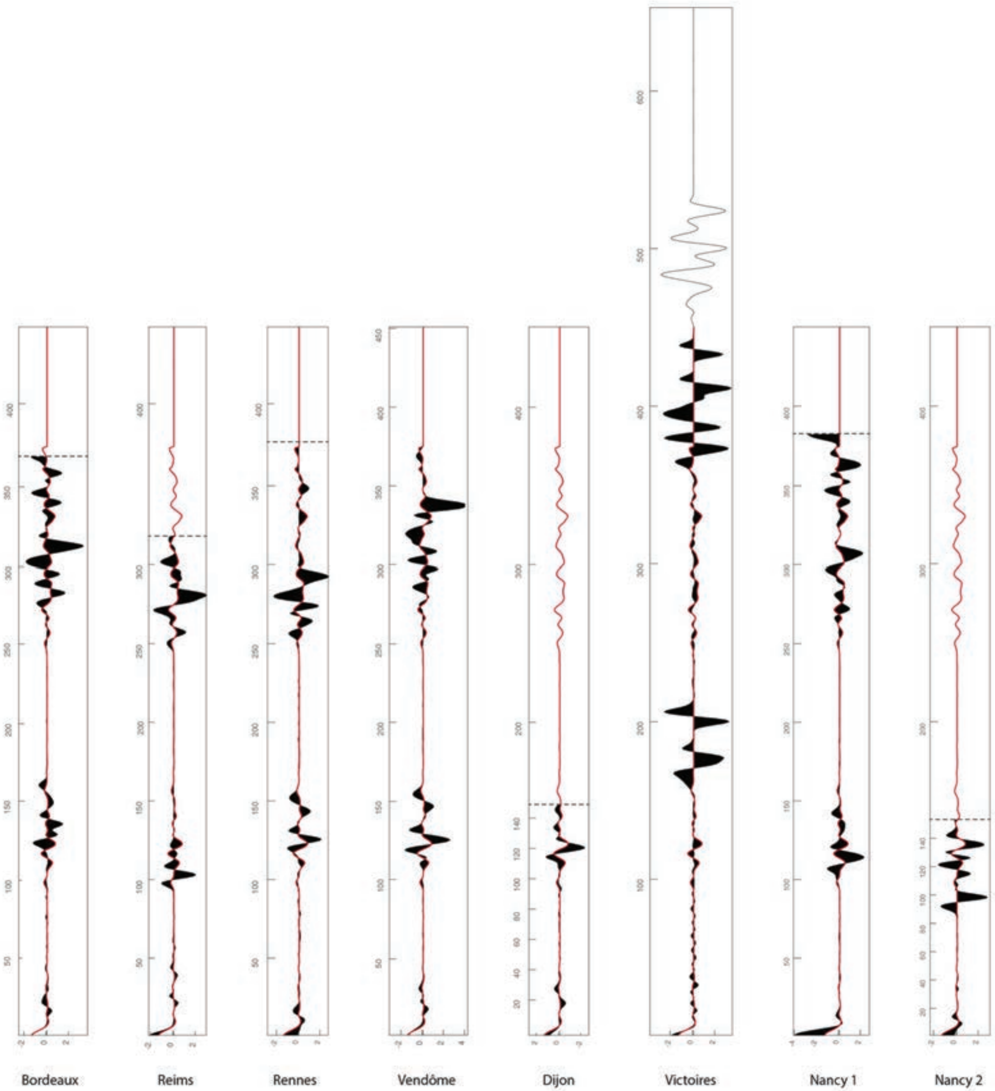

Fig. 7 - Similarities (and geometric deviations) of the signatures of each span with the average signature.

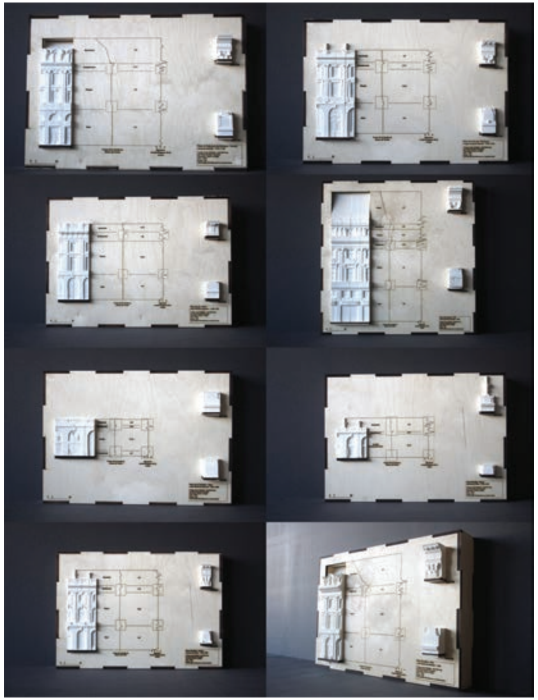

Fig. 8 - 3D printing of the 7 facades and identification of their semantic and geometric structure.

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hout, 1999; Shimada et al., 2004; Uhle, 1903). Pachacamac is not a city strictly speaking but a sanctuary, a pilgrimage place where for nearly 1500 years four pre-Columbian civilizations followed one another with as much evolution in its planning and organization until the arrival of the conquistadors.
Archaeological excavations began in Pachacamac in 1896 with archaeologist Max Uhle who drew up a detailed plan (fig. 9) that currently remains used by archaeologists as a basic document. The urban typology of Pachacamac is very complex and does not look like the typical ancient city of the Romans. The site appears to be organized around two main "streets" forming two axes and a concentric enclosures system extending from the most sacred at the south to the suburbs about 2km far to the north. The first axis is the North-South Street which crosses the site from the monumental gate to the Place Centrale. The second axis is the East-West Street which offers a route between different buildings with imposing walls. Several types of buildings with different functions such as temples, pyramids with ramps, warehouses, palaces, a convent, have been identified and are intertwined (fig. 10).
Apart from the two "streets" it is difficult to distinguish the possible routes through Pachacamac. Many questions remain on the relationships that existed between the different buildings as well as on the organization of the flow of pilgrims through routes designed to site and territory scale (Eeckhout, 2013). Indeed, given the uniform appearance of the site and the non-visible character of many buried buildings, it is sometimes difficult to realize the limits of the building and the pathways. The status of the site does not allow direct analyzes with tools of space syntax, and, distinguishing traffic areas from meeting areas or built areas requires to carry out such examinations (Battistin, 2021; Spence-Morrow, 2009).
Therefore, the focus here is to consider the contribution of the digitization of the site in terms of information to identify the possible routes within the site and beyond the visible. That is, beyond what the metric and colorimetric data show from the acquisition campaign. To do this, different methods of analyzing data from image analysis and statistics were implemented to highlight the morphological variations of the terrain.
A digital model of the status of the site was obtained from the low-altitude photogrammetric survey carried out by drone during two acquisition campaigns. Considering several types of representations improved the reading of the site, compared to what can be obtained from the ground. Superimposing different layers of data also enriched the images.
The first exported image from the model is an orthophotography like a map view (fig. 11). This type of image shows the site as it stands and allows for measuring immediate distances. Although the understanding of the site becomes easier with such an aerial view at a given scale, many details at the level of the built boundaries are still imperceptible. One technique to determine the presence of walls and buildings is the examination of micro-reliefs (Poirier et al., 2017) not directly visible to the naked eye on the site.
First, extracting a digital elevation model from the digitization provides information on the height of each of the points that form the image, although the 2D view (fig. 11). One solution to improve the buildings visualization was to play on the considered values and their color levels. Alternatively, to improve the understanding of the topography,

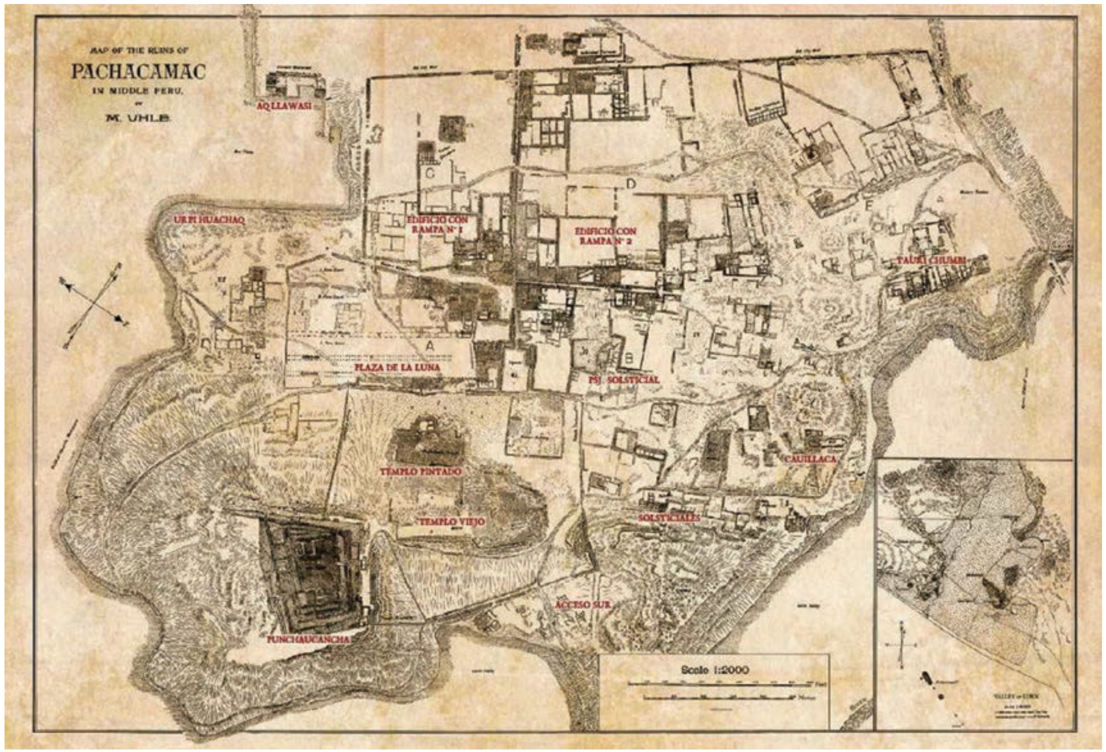

Fig. 9 - Plan of the monumental area of Pachacamac drawn up by Max Uhle (1903). Source: calameo.download.

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the micro-reliefs were stressed by integrating the level curves directly into a digital elevation model (DEM) and choosing the difference between these curves (fig. 11).
Another representation is a surface curvature map obtained by digitizing the site, allowing here for bringing out the micro-reliefs automatically and precisely and for identifying different types of surfaces. The green color indicates zero curvature, therefore a flat surface (without being horizontal), whereas red indicates a convex (or concave) surface, and blue shows a complex movement as a hyperbolic paraboloid. When walking around the site, it was difficult to perceive such variations or to determine if a mound of sand was the trace of an ancient wall. From the example on fig. 12, we clearly noted the presence of micro-reliefs that can be considered as walls (orange/red). Likewise, some green areas in the image might correspond to apparent places or paths. However, the interpretation of these surface curvature maps should be done with caution.
When crossing a digital elevation model (DEM) and a curvature map, the interpretation of the presence of a micro-relief becomes more plausible (fig. 13). This image has an additional height information which is not included in the curvature map, and has information on the type of surface, which is not provided by the elevation model, hence bringing consistency to the interpretation with respect to the data. As such, this last representation was found the most relevant for the present objective, involving (re)creating a model of a displacement network within Pachacamac.
By combining the information obtained from the data collected during the excavation campaigns, we were also able to qualify the different possible routes, to

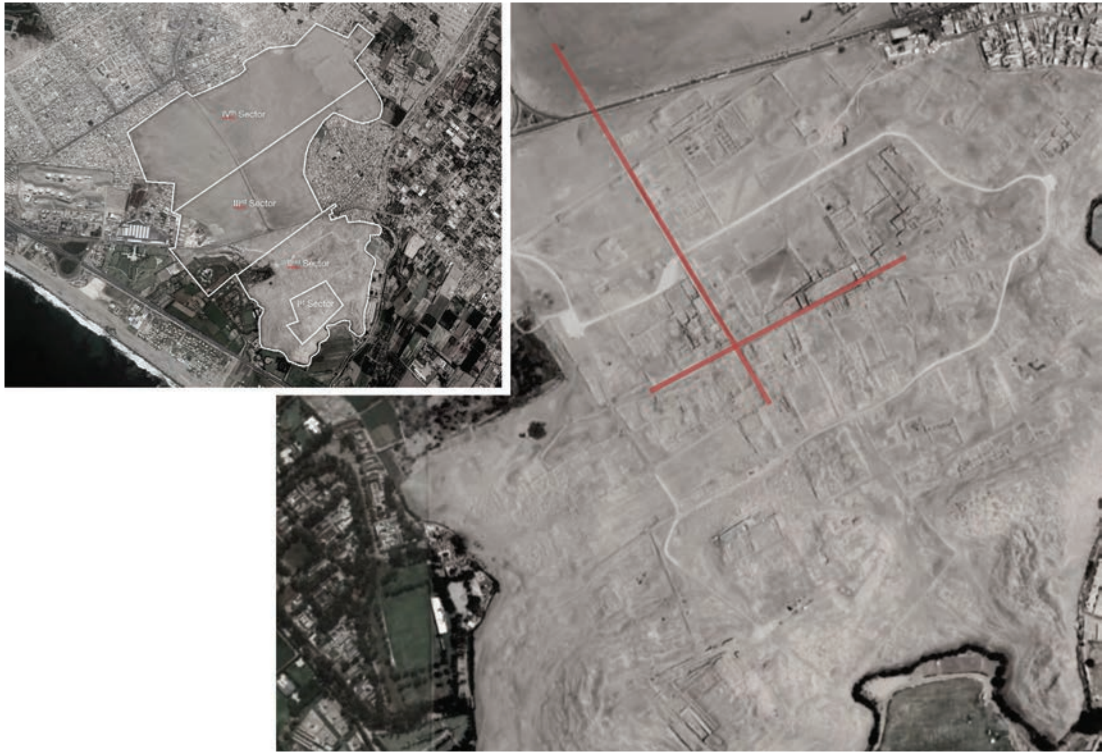

Fig. 10 - Left part: General aerial view of the Pachacamac site and its four sectors. Right part: Zoom on the monumental area with the two main traffic axes highlighted. Source: Google earth.

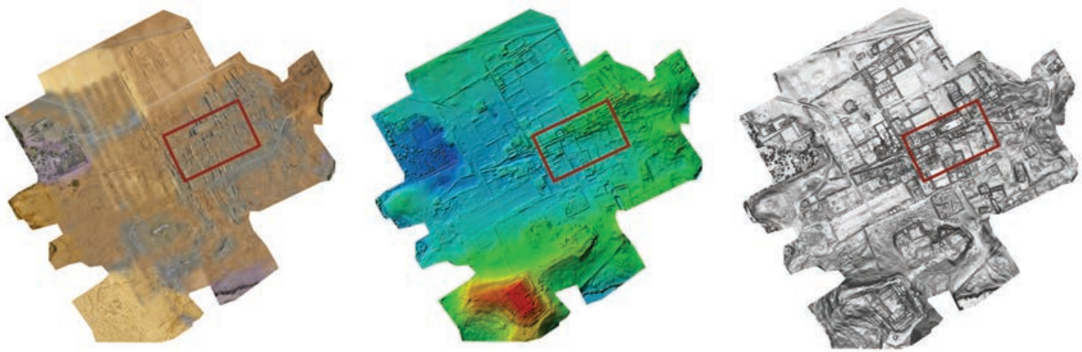

Fig. 11 - Left to right: Orthophotography from drone scanning / Digital Elevation Model (DEM), the elevation scale goes from blue (lowest) to red (highest) / Level curves from DEM. Area of study in the red rectangle.

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understand who may have used them, and thus shed light on the functional destination of the different buildings. Once the network is in place, the space syntax tools allow for carrying out inter-visibility, integration or even flow analyses (fig. 14) to prioritize the implicit sequences of the site and formulate the hypothesis of a scenography of the urban space based on a progressive sacralization of the route.

6. CONCLUSIONS

Without the observer's gaze, signatures have no intrinsic value. Neither artifacts nor "theoretical model", the interest of signatures lies in the questions they open. The exploitation of digitization and the formalization of morphological signatures offer new ways for the semi-automatic classification of architectural elements. If today the study is based on a corpus limited to a dozen columns (or a dozen facades) what if those were extended to a hundred? These explorations on semi-automatic analytical assistance methods and the "low level" approach developed here is justified by the current context of democratization of digitization tools, and, by the need of innovative methodologies for the exploitation of massive data. This present work provides first "toolboxes" for assisting in the characterization of architectural shapes and highlights the need to further investigate the modalities for extending these methods to other shape complexities or architectural typologies.
The opening of this research field and the application of this methodology on three architectural scales show the contribution of this approach to the communities concerned by the study of the built heritage. In addition to the possibilities of investigation for the study of morphological alterations, the "low level" methods also open for opportunities in the classification of architectural elements as well as in the study of stylistic propagations in space and time. At the level of the urban scale, and more particularly in the case of large-scale archaeological complexes, this "low level" approach can be considered as an additional tool for the identification of circulation networks through the site.

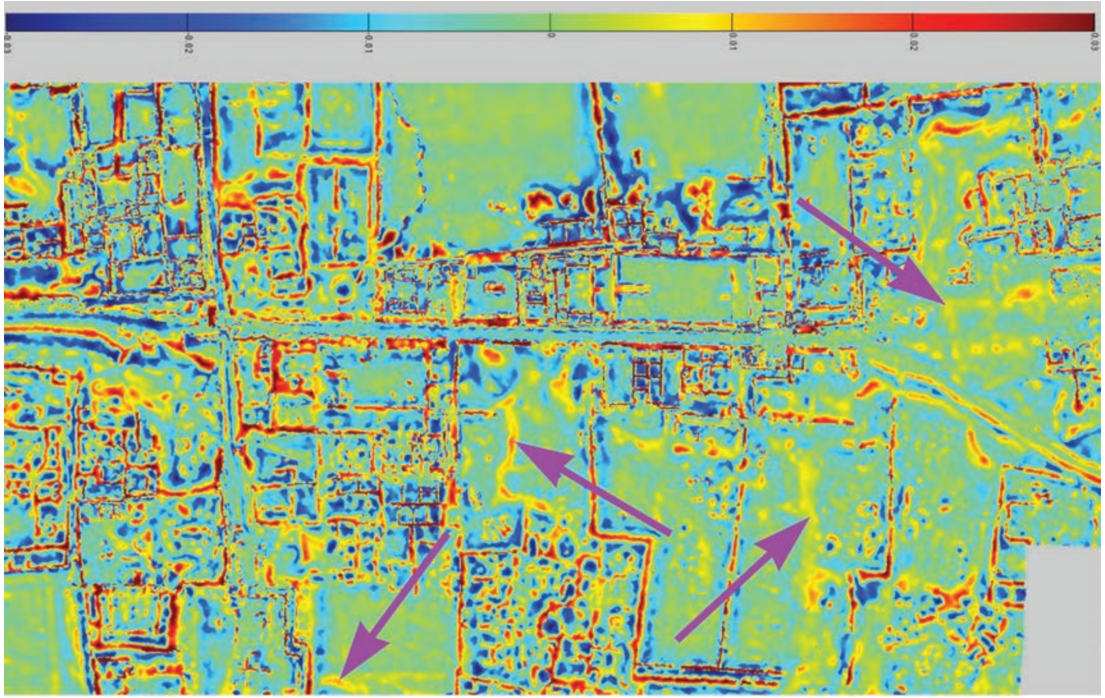
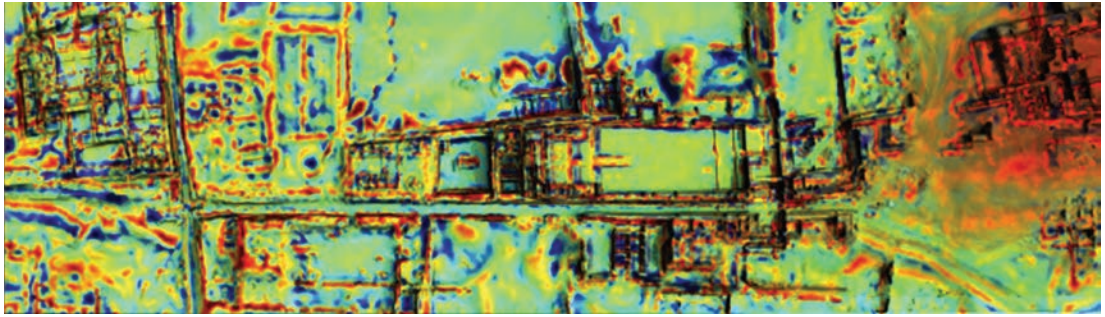


Fig. 12 - Curvature map on which the likely presence of structures that are difficult to perceive in the field are identified. This map was generated from the digital model acquired by aerial photogrammetric survey.

Fig. 13 - Superposition of a DEM and a curvature map. The idea is to combine several types of complementary morphological information into a single image.



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The use of shape analysis tools from other disciplinary fields demonstrates that the accumulation of data supports a certain form of intelligibility of the digital representations by renewing our look at architectural semantics. In many ways, the "particularity" is more illuminating about the series than the "standard" itself. This work of "return" analysis and the surprising nature of some observations cannot succeed without the existence of favorable conditions, those established by the creation of morphological signatures. This approach opens other forms of intelligibility. We can, in this sense, speak of a "low-level" intelligibility, an intelligibility of the clue, of the trace, of the anomaly. This study also highlights the need for expanding the examination to an important number of corpus in order to improve a generalization of the stylistic characterization. By multiplying the case studies on the different scales, mainly for the first two points, our approach allow to move forward on a reformulation of previously established styles.
At the level of urban complexes, it seems that a prerequisite of knowledge is necessary. Indeed, traffic has a cultural dimension which implies different modes of travel according to civilizations. The study of the networks should be extended to other urban archaeological contexts, even to unaltered contexts (the conservation status of the site may have an influence on the quality of the surveyed data) to validate the methodological relevance experimented in the present study.

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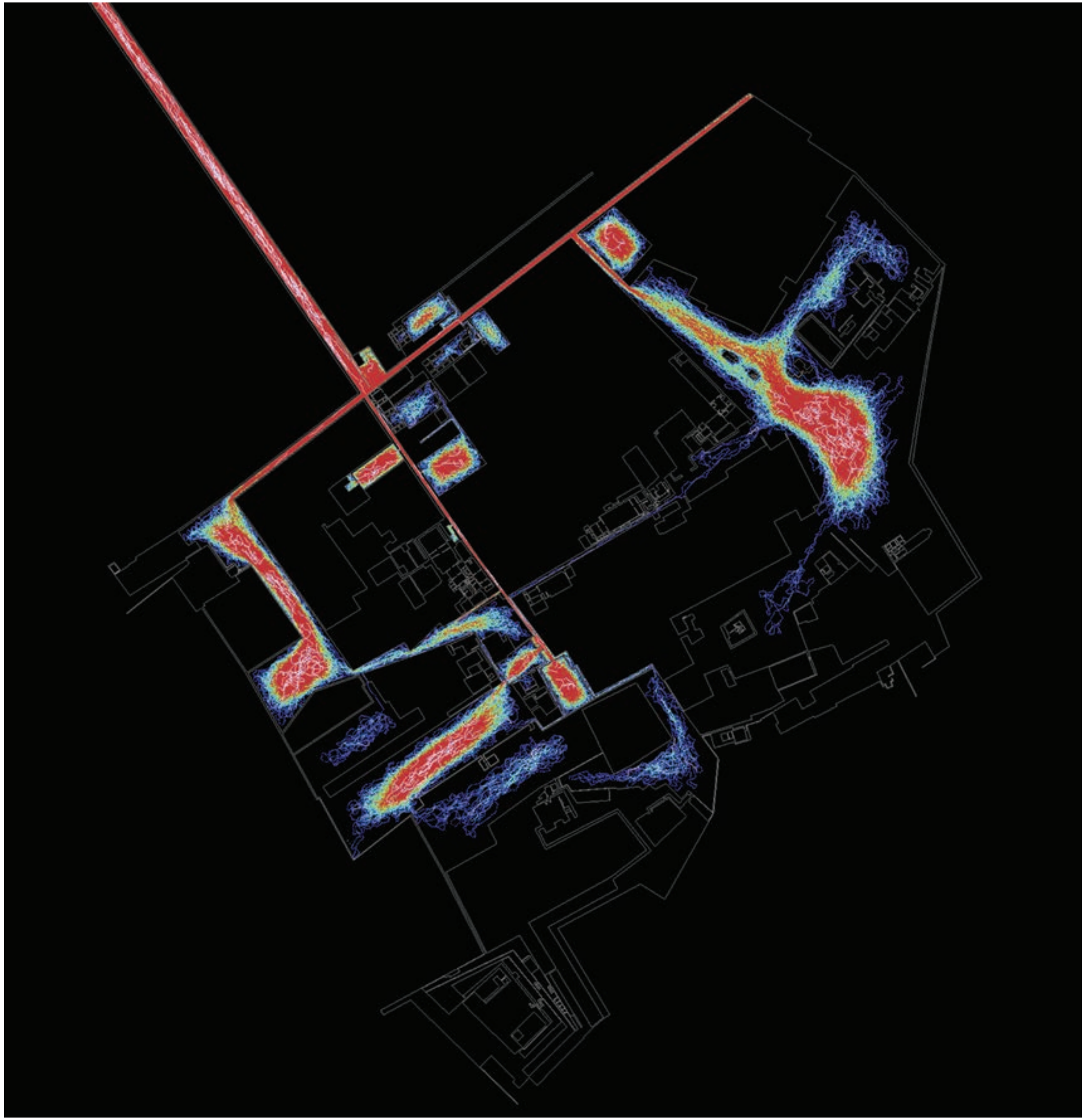

Fig. 14 - Crowd movement generation test. Image: Mathieu Jonckheere.

DOI: https://doi.org/10.20365/disegnarecon.26.2021.3

NOTE

[1] These games of knowledge around the building (or an architectural element) can concern its typology as much as its spatial-temporal evolution or its geometric and semantic characteristics.

[2] Since the Renaissance, architects such as Palladio, Vignole, Serlio and others more recently have worked to identify and describe the architecture of the past with the ambition of refining our view on the codification and evolution of architectural styles. In these treatises (or precise), often singular, the orders are described through the architectural elements that compose them, in terms of composition, geometry or semantics.

[3] In this case, the patterns correspond to homogeneous structures (or organization) of pixels in the image.

[4] As a reminder, the signatures of discontinuity and curvature are based on the statistical calculation of certain geometric properties of the columns.

[5] This study is based on the results of the experiments carried out as part of the master's thesis (September 2018, ULB) by Quincy-Jones Deldaele - Axel Ricbourg conducted under the supervision of David Lo Buglio.

[6] In the context of this study, the notion of intelligibility expresses the capacity of digitization (of the 3D representation or of the representation in a more general way) to refer to a universe of knowledge specific to the architectural field, to a universe able of us inform about the semantics of the object.

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